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Registrierung von Bilddaten

Enregistrement de données d'images

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(73) Proprietor: **BrainLAB AG**
85622 Feldkirchen (DE)

(72) Inventors:
- **Haimerl, Martin**
  82205 Gilching (DE)
- **Schindler, Florian**
  80937 München (DE)

(74) Representative: **Schwabe - Sandmair - Marx**
Patentanwälte
Stuntzstraße 16
81677 München (DE)

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Description

[0001] The present invention relates to registration systems and more particularly to a method and apparatus for registering a surgical object and a spatial representation of the object in three-dimensional space.

[0002] Imaging means available to date, such as computer tomography (CT) and magnetic resonance imaging (MRI), are less suited to be used during medical surgery. However, spatial representations of the body or body portions of a patient are indispensable in computer-assisted surgery (CAS), for instance.

[0003] It is therefore general custom to acquire spatial representations comprising serial sections acquired from CT or MRI scans prior to surgical interventions.

[0004] During surgery the patient or portions of interest of the patient have to be brought into alignment with pre-operatively acquired spatial representations of the patient or portions of the patient.

[0005] In particular two-dimensional imaging techniques are applied to match or register an object, the body of a patient or a body portion of a patient, for instance, to pre-operatively acquired spatial representations of the object.

[0006] US Patent no. 4,791,934 (Brunnett) describes a system, wherein the current actual position of a patient and diagnostic data comprising a spatial representation of a body portion of the patient are brought into registration by taking two-dimensional radiographic reference images of a body portion of interest from a selected spatial position and angular orientation (pose) of a radiographic imaging apparatus. Subsequently, a shadowgraphic image synthesizer is used to synthesize analogous shadowgraphic images from the diagnostic data forming a spatial representation of the body portion of interest. The synthetic images are taken from the same spatial position and angular orientation (pose) as the reference images. By adjusting the spatial position and angular orientation (pose) of the synthetic camera an optimal match between the superimposed reference and synthetic images is achieved. From the adjusted spatial position and angular orientation (pose) of the synthetic camera the pose of the spatial representation of the body portion of interest can be adjusted accordingly and thus been brought into alignment with the actual position of the patient.

[0007] In "A Comparison of Similarity Measures for Use in 2-D-3-D Medical Image Registration", IEEE Transactions on Medical Imaging, Vol. 17, No. 4, August 1998, Penney et al. describe alignment techniques to register pre-operative three-dimensional CT scans forming spatial representations of an object to intra-operatively acquired two-dimensional X-ray fluoroscopy images. By casting rays through a CT volume, integrating values derived from the volume elements (voxels) of the CT scan along the ray, and projecting them onto an imaging plane digitally reconstructed radiographs (DRRs) are produced that may resemble a radiograph. Penney et al. continue to describe various similarity measures between fluoroscopic reference images of an object and digitally reconstructed radiographs (DRRs) of a spatial object representation based on normalized cross-correlation of image pairs, on normalized cross-correlation of gradient filtered image pairs, and on entropy evaluation in a difference image between image pairs, for instance.

[0008] US Patent no. 5,951,475 (Gueziec et. al) describe a system for registering two-dimensional fluoroscopic images with a three-dimensional model of a surgical tissue of interest without using a digitally reconstructed radiographs (DRRs) with a bundle-adjustment technique using contours detected in the two-dimensional fluoroscopic images.

[0009] In "Intensity-Based 2D-3D Spine Image Registration Incorporating one Fiducial Marker", MICCAI 2003, pp. 287-294, 2003, Russakoff et al. propose the usage of an additional fiducial marker for the registration of a three-dimensional computed tomography (CT) image to one or more two-dimensional X-ray projection images. This method requires the implantation of a marker in the patient. An implanted fiducial marker is used as an additional pair point or corresponding point for the registration. An image similarity measure and a point distance are additively combined as an optimization measure for the registration. However, the additive combination of image similarity values and distance values within the optimization measure is not independent of the scaling of grey-level intensity values in the X-ray projection images. Thus, the registration procedure according to Russakoff et al. depends on variations in the image quality.

[0010] Huang X., Sun Y., Metaxas D., Sauer F. and Xu C. describe in the article "Hybrid Image Registration based on Configural Matching of Scale-Invariant Salient Region Features", Proceedings of the 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops, June 2004 (2004-06) pages 1-10, a Region Component Matching (RCPM) step. The likelihood of each hypothesized correspondence between region features is measured. Before the intensity similarity is measured, their scales are normalized by supersampling the smaller region to match the scale of the larger region, which leads to scale-invariant matching.

[0011] US 2004/0097806 A1 discloses an image guided catheter navigation system for cardiac therapies. It is described that a physician selects and stores particular points from pre-acquired images and then touches the corresponding points on the patient's anatomy with a pointer probe to register the patient.

[0012] In conventional 2D/3D registration of the pelvis, for instance, usually two fluoroscopic images are acquired. With known techniques minor directional errors in the alignment of the pubis may lead to significant errors in the acetabulum and spina region. In order to be suited to hip surgeries, for instance, very accurate registration especially in these areas is required.

[0013] It is an object of the present invention to improve the accuracy of inter-operative registration methods and systems for registering an object or portion of an object to a spatial representation of the object or portions thereof.

[0014] This object is achieved by a method and a device comprising the features of the independent claims. Preferred embodiments arise from the dependent claims.

[0015] The method and system according to the invention for registering pre-operatively acquired three-dimensional patient data with an actual position of the patient in the operating room dispenses entirely with the use of fiducial markers which hitherto have been employed to improve registration accuracy. Fiducial markers may be a metallic element usually implanted in bone regions of a patient requiring a surgical implantation procedure.

[0016] In contrast to methods of known art the inventive method and system does not require the implantation of such markers.

[0017] The inventive method uses an additional constraint, which may significantly improve the accuracy as well as the robustness of the registration of an object in the operating room to a data representation of the object.

[0018] An additional constraint for the registration according to the invention is obtained by acquiring in a three-dimensional coordinate system, preferably a Cartesian coordinate system, related to the operating environment a location of at least one point on the surface of a bone region, for instance, which may be the spina or acetubulum region. Since these regions cover relatively large areas rotational errors may be largely reduced.

[0019] The inventive method integrates the surface-based information into 2D-3D-registration techniques (in particular matching of CT-fluoroscopic images). An object has to be registered by means of acquired 2D image data and 3D image data (e.g. fluoroscopic images and a 3D CT scan) and one or more additional surface points.

[0020] The object to be registered may be a patient or body portions of a patient in diagnostic, therapeutic, clinical or automatic examination or treatment.

[0021] The inventive method integrates surface-based information registration techniques based on imaging data, e.g. 2D-3D-registration techniques (in particular matching of CT-fluoroscopic images). An object has to be registered by means of the operatively acquired 2D image data and into operatively acquired 3D image data (e.g. fluoroscopic images and a 3D CT scan) and one or more additional surface points.

[0022] Prior to acquiring a surface point or surface points on a bone region of the patient, for instance, the patient may be immobilized. Alternatively relative movements or dislocations of the patient may be acquired by a position sensing system or a navigation system. These relative dislocations may then be taken into account in the registration method and system according to the invention by adjusting the position and orientation (pose) of the spatial data representing the patient accordingly.

[0023] A method according to the invention of determining in a three-dimensional operating space a measure of super-imposition M between an object or a portion thereof, referred to as object, and a spatial representation of the object, referred to as object representation, in an object representation pose, a pose comprising position and orientation in operating space, may comprise:

a) obtaining a similarity measure S between the first imaging data taken in first respective imaging poses of the object and second image data comparable to the first imaging data taken in second respective imaging poses which are digitally reconstructed image data from the object representation in the object representation pose,

b) locating in operating space at least one point on the surface of the object; and

c) obtaining a distance measure D between the at least one point in operating space and a surface of the object representation in the object representation pose, and the method further comprises:

obtaining a measure of superimposition M by a multiplicative combination of the similarity measure S and the distance measure D which is scale invariant with respect to the similarity measure S.

[0024] An apparatus according to the invention in a three-dimensional operating space an object or a portion thereof, referred to as object, and a spatial representation of the object, referred to as object representation, in an object representation pose, a pose comprising position and orientation in operating space, the apparatus comprising:

a first device for taking in first respective imaging poses first imaging data of the object;

a second device for taking in second respective imaging poses second imaging data comparable to the first imaging data which are digitally reconstructed from the object representation in the object representation pose;

a third device for obtaining a similarity measure S between the first and second imaging data;

a fourth device for locating in operating space at least one point on the surface of the object;

a fifth device for obtaining a distance measure D between the at least one point and a surface of the object representation in the object representation pose;

a sixth device for obtaining a measure of superimposition M by a multiplicative combination of the similarity measure S and the distance measure D which is scale invariant with respect to the similarity measure S;

a seventh device for changing the object representation pose to a different pose relative to the second respective imaging poses and

an eighth device for determining whether two consecutive measures of superimposition M for different poses of the object representation obtainable from the sixth device approach one another up to a predetermined threshold.

[0025] In the method and system according to the invention the similarity measure S and the distance measure D may be combined to a measure of superimposition M as

$$M = S/(a + D),$$

wherein a is a predetermined constant.

[0026] In the method and system according to the invention scale invariance at least with respect to the similarity measure S may comprise scale invariance in ordering relations between measures of superimposition M at least with respect to the similarity measure S.

[0027] In the method and system according to the invention relative dislocations of the object may be acquired via a pointer (150) fitedly attached to the object by means of a position sensing or a navigation system, for instance and the pose of the object representation may be adapted accordingly.

[0028] In the method and system according to the invention the spatial representation of the object may comprise a decision rule and plurality of volume elements, referred to as voxels, piled up in slices comprising rows and columns, each voxel carrying at least one value, and the decision rule determining the membership of each voxel to the object in accordance with the at least one value of the voxel.

[0029] In the method and system according to the invention voxels may be obtained from imaging devices using computed tomography (CT), magnetic resonance (MR), single photon emission computed tomography (SPECT), or positron emission tomography (PET).

[0030] In the method and system according to the invention reference image data taken of the object or portions of the object comprise imaging data, e.g. ultrasound or fluoroscopy radiographs which may be compared with digitally reconstructed imaging data, e.g. digitally reconstructed radiographs (DRRs). Imaging poses of the reference radiographs are preferably assuming essentially the same positions and orientations relative to each other as the respective imaging process of the reconstructed imaging data, e.g. DRRs. Further preferably the geometry of the imaging device or devices used to take the reference radiographs is essentially identical to the geometry of the virtual or synthetic imaging devices used to take the reconstructed imaging data.

[0031] In the method and system according to the invention the similarity measure S between the first and second image data may be obtained by correlating corresponding pairs of first and second imaging data, and/or wherein the distance measure D between the at least one point and a surface of the object representation in its pose may be obtained by the Euclidean distance of the point and the surface of the object representation in the case of a single point and otherwise by averaging the Euclidean distances of more than one point and the surface of the object representation.

[0032] In the method and system according to the invention a one point or points on the surface of the object may be located using a position sensing system or a navigation system.

[0033] The method according to the invention may further be executed by a computer program executed on a general purpose computer, a dedicated computer or a computer on a chip (SOC).

[0034] Further a computer may be caused by a computer program to function as the apparatus according to the invention.

[0035] The computer program for executing the method in accordance with the invention and/or the computer program causing a computer to function according to the apparatus in accordance with the invention may be stored on a computer-readable data carrier.

[0036] The invention will be described for a specific embodiment by way of the figures, which show

Figur 1 a schematic representation of the application of the inventive method of registering an object or a portion of an object to a spatial representation of the object or a portion of the object;

Figur 2 a flowchart of an embodiment of the method in accordance with the invention.

[0037] Figur 1 shows in diagrammatic form a portion of an object 100, for instance the pelvis of a patient. A spatial representation (not shown) may have been preoperatively acquired by means of a computer tomograph 121 and stored in a computer system 180. During surgery two-dimensional fluoroscopic images 110 may be acquired by an imaging system 120 comprising an X-ray source 125. Alternatively other imaging data may be acquired by suitable imaging means such as ultrasound images for example. The imaging system 120 may be navigated, i.e. its positional and orientational dislocations in the operating room (not shown) may be controlled and/or registered by the computer system 180. Alternatively, the imaging system 120 may comprise active or passive elements indicative of a position of the imaging system 120 and observed by one ore more cameras 130 which may be operatively coupled to the computer system 180.

[0038] A marker (153) may be used to acquire relative dislocations of the object by means of the position sensing system 130, for instance.

[0039] In addition to the fluoroscopic images 110 taken by the imaging system 120 a pointer 150 comprising a tip 151 and position signalling elements 152 which are tracked by means of the at least one camera 130. A point or points on the surface of the object, for instance on the surface of the pelvis 100 of the patient are located by means of guiding the tip of the pointer to a desired position or positions. A tracking system comprising the pointer 150 and the at least one camera 130 determines the location of the indicated point or points in three-dimensional coordinate system related to the operating environment.

[0040] The registration method 190 according to the invention may be executed by means of the computer system 180. The registration is computed by a known optimisation technique which optimises a given optimisation measure. The parameters for optimisation are specified by a relation between the 2D domain and the 3D domain. After fluoroscopic images 110 have been taken with a X-ray / fluoroscopic imaging device 120, for instance and surface points on the surface of the object have been taken, the corresponding data are stored in the computer system 180. In the computer system 180 digitally reconstructed radiographs (DRRs) are generated and stored in the computer system 180 from a spatial representation of the object (not shown) which is also stored in the computer system 180, using the position and orientation of the X-ray source 125 of the imaging system 120 which are also stored in the computer system 180. Next a similarity measure S between the X-ray / fluoroscopic images 110 and the digitally reconstructed radiographs (not shown) is obtained by means of instructions executed in the computer system 180, for instance.

[0041] Subsequently a distance measure D between the at least one point acquired on the surface of the object in a three-dimensional coordinate system related to the operating environment and a surface of the object representation (not shown) is obtained by taking into account the current position and orientation (pose) of the spatial representation of the object (not shown). Then, the similarity measure S and the distance measure D are combined to a measure of superimposition 11 according to the following equation, for instance;

$$M = S/(a+D)$$

a is a predetermined non-vanishing constant.

[0042] The inventive combination of the similarity measure S, e.g. a CT-fluoroscopic optimisation measure, and the distance measure D, e.g. a surface distance term, uses in one embodiment a multiplicative combination of S and D. Due to the combination of S and D to a measure of superimposition M according to the invention an optimisation with respect to the measure of superimposition M gets scale invariant with respect to a preferable, montotoneus function f (D), where f (D) = 1 /(const + D), for instance. Both S and 1 /(a+D) positively assess favourable positions and/or orientations. In particular, the inventive method yields an invariance with respect to the scaling of greylevels in the fluoroscopic images as well as in the CT data of the spatial representation of the object.

[0043] Usually a standardised scaling for the image intensity values is not available. Therefore, it is important to provide a scale invariant optimisation procedure with respect to the similarity term S. For this purpose a multiplicative combination of S and D is provided by the inventive method and system.

[0044] Depending on the value of the measure of superimposition M obtained as described above, the position and orientation (pose) of the object representation may be changed or adjusted to assume a different position and/or orientation in the three-dimensional coordinate system related to the operating environment. Alternatively, it might be convenient for a user of the inventive method and system to adjust the position and orientation (pose) of a virtual or synthetic camera by means of which the digitally reconstructed radiographs (DRRs) are taken. In this embodiment of the invention the pose of the spatial representation of the object will be changed according to the change of the pose of the virtual or synthetic camera which is used to take the digitally reconstructed radiographs (not shown).

[0045] Referring now to Fig. 2, wherein a flow diagram shows the general principle used in the registration system shown in Figure 1 or in the method according to the invention for registering an object or a portion of an object and a spatial representation of the object or a portion of the object in three-dimensional space, wherein a spatial representation of the object or a portion of the object is assumed to be in a know initial position and orientation (pose) related to the operating environment.

[0046] It is assumed that a spatial representation of the object in a known position and orientation (pose) in a three-dimensional operating space has been acquired preoperatively 310.

[0047] In step 320 reference image data, for example radiographs of the object are taken with a navigated X-ray/fluoroscopic imaging system as shown in Fig. 1, for instance.

[0048] Subsequently a point or a number of points is located 330 on the surface of the object in operating space.

[0049] For simplicity the embodiment of the registration method according to the invention shown in Figure 2 incorporates a straight forward optimisation procedure which starting from an initial pose of the object representation obtains an optimal pose P as the pose with the biggest value of the measure of superimposition M which is obtained in a predeterment number of iterations of steps 340 to 380

[0050] P and M_{sup} are initialised in step 335 before the iteration starts.

[0051] The iteration comprising steps counting from 0 to 50, for instance, according to step 336.

[0052] In each iteration reconstructed imaging data, for example digitally reconstructed radiographs (DRRs) of the object representation in the current pose are obtained by casting rays through the spatial object representation and integrating the volume elements hit by any ray to form 340 reconstructed radiograph, for instance.

[0053] In step 350 a similarity measure S is obtained between the reference image data and the digitally reconstructed image data (DRRs) of the previous step. In step 355 a distance measure D is obtained between one or more points and a surface of the object representation in its incurrent pose.

[0054] The object may be represented by a decision rule and a plurality of volume elements (voxels) piled up in slices comprising rows and columns, each voxel carrying at least one value, and the decision rule determining the membership of each voxel to the object in accordance with the at least one value of the voxel. In such a representation of an object or a portion of an object a surface of the object representation may be obtained by threshholding the value or value of each voxel at a pre-determined value. Using known techniques, a distance between a point in operating space and surface voxels of the object representation may be obtained with sub-voxel accuracy period.

[0055] In step 360 the similarity measures S and the distance measure D are combined to a measure of superimposition M = S/ (const + D)

[0056] In step 370 it is determined whether the measure of superimposition M exceeds the current maximum M_{sub} and if so, YES in step 370, the optimized pose P is set to the current pose and the maximum measure of superimposition M_{sub} is set to the current measure of superimposition M in step 375.

[0057] In the case where the current measure of superimposition M does not exceed the maximum value M_{sub}, NO in step 370, or after completion of the updating step 375 the current pose of the object representation is changed to a different position and orientation and the optimizing iteration controlled by the court in step 336 is continued by an execution of step 340 to 380 is continued.

[0058] In each step of the iteration or optimisation artificial images are rendered from the 3D data set (according to the current pose or parameter settings) and compared with the 2D data set.

[0059] After completing a pre-determined number of iterations the registration procedure according to the invention is terminated resulting in a pose P that registers the object representation with an actual position of the object in operating space.

[0060] Alternative convergence criteria for terminating the iteration of steps 340 to 380 may comprise the determination whether the measure of superimposition M in a given iteration exceeds a predetermined threshold.

Claims

1. Method of determining in a three-dimensional operating space a measure of superimposition M between an object or a portion thereof, referred to as object, and a spatial representation of the object, referred to as object representation, in an object representation pose, a pose comprising position and orientation in operating space, the method comprising:

    step a) taking in first respective imaging poses first imaging data of the object;
    step b) taking in second respective imaging poses second imaging data comparable to the first imaging data which are digitally reconstructed from the object representation in the object representation pose;
    step c) obtaining a similarity measure S between the first and second imaging data;
    step d) acquiring in operating space a position of at least one point indicated on the surface of the object;
    step e) obtaining a distance measure D between a position of the at least one point in operating space and a surface of the object representation in the object representation pose, and **characterized in that** the method further comprises:
    step f) obtaining a measure of superimposition M by a multiplicative combination of the similarity measure S and the distance measure D;
    wherein the combination of the similarity measure S and the distance measure D is scale invariant with respect to the similarity measure S.

2. Method according to the preceding claim further comprising registering the object and the object representation pose in operating space, including the steps:

    step
    step g) jointly performing step h) and repeating steps b), c), e), and f) a predetermined number of times or until two consecutive measures of superimposition M obtained in step f) approach one another up to a predetermined threshold or until a predetermined convergence criterion is met; and
    step h) changing the object representation pose to a different pose relative to the second respective imaging poses.

3. Method according to any of the preceding claims, wherein the first imaging data are acquired inter-operatively and/or the second imaging data are reconstructed from a pre-operatively acquired object representation.

4. Method according to any of the preceding claims, wherein the similarity measure S and the distance measure D are combined to the measure of superimposition M as

$$M = S/(a + D),$$

wherein a is a predetermined constant.

5. Method according to any of the preceding claims, wherein scale invariance at least with respect to the similarity measure S comprises scale invariance in ordering relations between measures of superimposition M at least with respect to the similarity measure S.

6. Method according to any of the preceding claims, further comprising:

   acquiring relative dislocations of the object, and adapting the object representation pose accordingly.

7. Method according to the preceding claim, wherein the relative dislocations of the object are acquired via a marker (153) fixedly attached to the object by means of a position sensing system or a navigation system.

8. Method according to any of the preceding claims, wherein the object is a body of a patient.

9. Method according to any of the preceding claims, wherein the spatial representation of the object comprises a decision rule and plurality of volume elements, referred to as voxels, piled up in slices comprising rows and columns, each voxel carrying at least one value, and the decision rule determining the membership of each voxel to the object in accordance with the at least one value of the voxel.

10. Method according to the preceding claim, wherein the voxels are obtained from imaging the object using computed tomography (CT), magnetic resonance (MR), single photon emission computed tomography (ASPECT), or positron emission tomography (PET).

11. Method according to any of the preceding claims, wherein the first imaging data comprise ultrasound images or fluoroscopy radiographs and the second radiographs comprise digital reconstructed images or digitally reconstructed radiographs (DRRs), and/or wherein the first respective imaging poses are assuming essentially the same position and orientations relative to each other as the second respective imaging poses.

12. Method according to any of the preceding claims, wherein the similarity measure S between the first and second imaging data is obtained by correlating corresponding pairs of first and second imaging data, and/or wherein the distance measure D between the at least one point and a surface of the object representation in the object representation pose is obtained by the Euclidean distance of the point and the surface of the object representation in the case of a single point and otherwise by averaging the Euclidean distances of more than one point and the surface of the object representation.

13. Method according to any of the preceding claims, wherein the at least one point on the surface of the object is located using a position sensing system or a navigation system.

14. Apparatus for registering in a three-dimensional operating space an object (100) or a portion thereof, referred to as object, and a spatial representation of the object, referred to as object representation, in an object representation pose, a pose comprising position and orientation in operating space, the apparatus comprising:

   a first device for taking in first respective imaging poses first imaging data (110) of the object;
   a second device for taking in second respective imaging poses second imaging data comparable to the first imaging data which are digitally reconstructible from the object representation in the object representation pose;
   a third device for obtaining a similarity measure S between the first and second imaging data;
   a fourth device for acquiring in operating space a position of at least one point indicatible on the surface of the object;
   a fifth device for obtaining a distance measure D between the at least one point and a surface of the object representation in the object representation pose;
   a sixth device for obtaining a measure of superimposition M by a multiplicative combination of the similarity measure S and the distance measure D which is scale invariant with respect to the similarity measure S;
   a seventh device for changing the object representation pose to a different pose relative to the second respective imaging poses and
   an eighth device for determining whether two consecutive measures of superimposition M for different poses of the object representation obtainable from the sixth device approach one another up to a predetermined threshold, or meet a predetermined convergence criterion.

15. Apparatus according to the preceding claim, wherein the first imaging data are interoperatively acquirable and/or the second imaging data are reconstructible from a pre-operatively acquirable object representa-

tion.

16. Apparatus according to the two preceding claims, wherein the similarity measure S and the distance measure D are combinable to the measure of superimposition M as

$$M = S/(a + D),$$

wherein a is a predetermined constant.

17. Apparatus according to any of the three preceding claims, wherein scale invariance at least with respect to the similarity measure S comprises scale invariance in ordering relations between measures of superimposition M at least with respect to the similarity measure S.

18. Apparatus according to any of the four preceding claims, further comprising:

a ninth device for acquiring relative dislocations of the object, and
a tenth device for adapting the object representation pose accordingly.

19. Apparatus according to any of the five preceding claims, wherein the relative dislocations of the object are acquirable via a marker (153) fixedly attached to the object by means of a position sensing system or a navigation system.

20. Apparatus according to any of the six preceding claims, wherein the object is a body of a patient.

21. Apparatus according to any of the seven preceding claims, wherein the spatial representation of the object comprises a decision rule and plurality of volume elements, referred to as voxels, piled up in slices comprising rows and columns, each voxel carrying at least one value, and the decision rule determining the membership of each voxel to the object in accordance with the at least one value of the voxel.

22. Apparatus according to the preceding claim, wherein the voxels are obtainable from imaging devices using computed tomography (CT), magnetic resonance (MR), single photon emission computed tomography (SPECT), or positron emission tomography (PET).

23. Apparatus according to any of the nine preceding claims, wherein the first imaging data comprise ultrasound images or fluoroscopy radiographs and the second imaging data comprise digitally reconstructed images or digitally reconstructed radiographs (DRRs), and/or wherein the first respective imaging poses are assuming essentially the same positions and orientations relative to each other as the second respective imaging poses.

24. Apparatus according to any of the ten preceding claims, wherein the similarity measure S between the first and second imaging data is obtainable by correlating corresponding pairs of first and second imaging data, and/or wherein the distance measure D between the at least one point and a surface of the object representation in the object representation pose is obtainable by the Euclidean distance of the point and the surface of the object representation in the case of a single point and otherwise by averaging the Euclidean distances of more than one point and the surface of the object representation.

25. Apparatus according to any of the eleven preceding claims, wherein the at least one point on the surface of the object is locatable using a position sensing system or a navigation system.

26. A computer program product comprising program code means for executing the method steps according to any of claims 1 to 13, when the program is executed on a computer, or for causing a computer to function as the apparatus according to any one of claims 14 to 25, when the program is executed on a computer.

27. A computer program product comprising program code means according to the preceding claim that are recorded on a computer-readable data carrier.

Patentansprüche

1. Verfahren zum Bestimmen eines Maßes der Überlagerung M zwischen einem Objekt oder einem Anteil davon, die als Objekt bezeichnet werden, und einer räumlichen Darstellung des Objekts, die als Objektdarstellung bezeichnet wird, in einer Objektdarstellungs-Haltung in einem dreidimensionalen Betriebsraum, wobei eine Haltung eine Position und eine Orientierung im Betriebsraum umfasst, wobei das Verfahren umfasst:

Schritt a) Aufnehmen in ersten jeweiligen Abbildungshaltungen erster Abbildungsdaten des Objekts;
Schritt b) Aufnehmen in zweiten jeweiligen Abbildungshaltungen zweiter Abbildungsdaten, die mit den ersten Abbildungsdaten vergleichbar sind, die aus der Objektdarstellung in der Objektdarstellungs-Haltung digital rekonstruiert werden;
Schritt c) Erhalten eines Ähnlichkeitsmaßes S zwischen den ersten und den zweiten Abbil-

dungsdaten;
Schritt d) Erfassen einer Position wenigstens eines Punktes, der auf der Oberfläche des Objekts angegeben ist, im Betriebsraum;
Schritt e) Erhalten eines Abstandsmaßes D zwischen einer Position des wenigstens einen Punktes im Betriebsraum und einer Oberfläche der Objektdarstellung in der Objektdarstellungs-Haltung,
dadurch gekennzeichnet, dass das Verfahren ferner umfasst:

Schritt f) Erhalten eines Maßes der Überlagerung M durch eine multiplikative Kombination des Ähnlichkeitsmaßes S und Abstandsmaßes D;
wobei die Kombination des Ähnlichkeitsmaßes S und des Abstandsmaßes D bezüglich des Ähnlichkeitsmaßes S maßstabsinvariant ist.

2. Verfahren nach dem vorhergehenden Anspruch, das ferner das Registrieren des Objekts und der Objektdarstellungs-Haltung in einem Betriebsraum umfasst und das die folgenden Schritte enthält:

Schritt g) gemeinsames Ausführen des Schrittes h) und Wiederholen der Schritte b), c), e) und f) in einer vorgegebenen Anzahl oder bis zwei aufeinanderfolgende Maße der Überlagerung M, die im Schritt f) erhalten werden, sich einander bis zu einem vorgegebenen Schwellenwert nähern oder bis ein vorgegebenes Konvergenzkriterium erfüllt ist; und
Schritt h) Ändern der Objektdarstellungs-Haltung in eine andere Haltung bezüglich der zweiten jeweiligen Abbildungshaltungen.

3. Verfahren nach einem der vorhergehenden Ansprüche, wobei die ersten Abbildungsdaten interoperativ erfasst werden und/oder die zweiten Abbildungsdaten aus einer voroperativ erfassten Objektdarstellung rekonstruiert werden.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Ähnlichkeitsmaß S und das Abstandsmaß D als

$$M = S/(a + D)$$

zu dem Maß der Überlagerung M kombiniert werden, wobei a eine vorgegebene Konstante ist.

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Maßstabsinvarianz wenigstens bezüglich des Ähnlichkeitsmaßes S die Maßstabsinvarianz in den Ordnungsrelationen zwischen den Maßen der Überlagerung M wenigstens bezüglich des Ähnlichkeitsmaßes S umfasst.

6. Verfahren nach einem der vorhergehenden Ansprüche, das ferner umfasst:

Erfassen der relativen Verschiebungen des Objekts, und
dementsprechendes Anpassen der Objektdarstellungs-Haltung.

7. Verfahren nach dem vorhergehenden Anspruch, wobei die relativen Verschiebungen des Objekts über eine Markierung (153), die fest an dem Objekt befestigt ist, mittels eines Positionsabtastsystems oder eines Navigationssystems erfasst werden.

8. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Objekt ein Körper eines Patienten ist.

9. Verfahren nach einem der vorhergehenden Ansprüche, wobei die räumliche Darstellung des Objekts eine Entscheidungsregel und mehrere Volumenelemente, die als Voxel bezeichnet werden und die in Scheiben aufgestapelt sind, die Zeilen und Spalten umfassen, umfasst, wobei jedes Voxel wenigstens einen Wert führt und die Entscheidungsregel die Mitgliedschaft jedes Voxels in dem Objekt in Übereinstimmung mit dem wenigstens einen Wert des Voxels bestimmt.

10. Verfahren nach dem vorhergehenden Anspruch, wobei die Voxel aus der Abbildung des Objekts unter Verwendung der Computertomographie (CT), der Magnetresonanz (MR), der Einzel-Photon-Emissionscomputertomographie (SPECT) oder der Positronenemissionstomographie (PET) erhalten werden.

11. Verfahren nach einem der vorhergehenden Ansprüche, wobei die ersten Abbildungsdaten Ultraschallbilder oder Fluoroskopie-Radiogramme umfassen und die zweiten Radiogramme digital rekonstruierte Bilder oder digital rekonstruierte Radiogramme (DRRs) umfassen und/oder wobei die ersten jeweiligen Abbildungshaltungen im Wesentlichen die gleiche Position und die gleichen Orientierungen relativ zueinander wie die zweiten jeweiligen Abbildungshaltungen annehmen.

12. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Ähnlichkeitsmaß S zwischen den ersten und den zweiten Abbildungsdaten durch das Korrelieren entsprechender Paare der ersten und der zweiten Abbildungsdaten erhalten wird und/oder wobei das Abstandsmaß D zwischen dem wenigstens einen Punkt und einer Oberfläche der Objekt-

darstellung in der Objektdarstellungs-Haltung durch den euklidischen Abstand zwischen dem Punkt und der Oberfläche der Objektdarstellung in dem Fall eines einzelnen Punktes und andernfalls durch das Mitteln der euklidischen Abstände zwischen mehr als einem Punkt und der Oberfläche der Objektdarstellung erhalten wird.

13. Verfahren nach einem der vorhergehenden Ansprüche, wobei der wenigstens eine Punkt auf der Oberfläche des Objekts unter Verwendung eines Positionsabtastsystems oder eines Navigationssystems lokalisiert wird.

14. Vorrichtung zum Registrieren eines Objekts (100) oder eines Anteils davon, die als Objekt bezeichnet werden, und einer räumlichen Darstellung des Objekts, die als Objektdarstellung bezeichnet wird, in einer Objektdarstellungs-Haltung, wobei eine Haltung eine Position und eine Orientierung im Betriebsraum umfasst, in einem dreidimensionalen Betriebsraum, wobei die Vorrichtung umfasst:

eine erste Vorrichtung zum Aufnehmen in ersten jeweiligen AbbildungsHaltungen erster Abbildungsdaten (110) des Objekts;
eine zweite Vorrichtung zum Aufnehmen in zweiten jeweiligen AbbildungsHaltungen zweiter Abbildungsdaten, die mit den ersten Abbildungsdaten vergleichbar sind, die aus der Objektdarstellung in der Objektdarstellungs-Haltung digital rekonstruierbar sind;
eine dritte Vorrichtung zum Erhalten eines Ähnlichkeitsmaßes S zwischen den ersten und den zweiten Abbildungsdaten;
eine vierte Vorrichtung zum Erfassen einer Position wenigstens eines Punktes, der auf der Oberfläche des Objekts angeben werden kann, in einem Betriebsraum;
eine fünfte Vorrichtung zum Erhalten eines Abstandsmaßes D zwischen dem wenigstens einem Punkt und einer Oberfläche der Objektdarstellung in der Objektdarstellungs-Haltung;
eine sechste Vorrichtung zum Erhalten eines Maßes der Überlagerung M durch eine multiplikative Kombination des Ähnlichkeitsmaßes S und des Abstandsmaßes D, die bezüglich des Ähnlichkeitsmaßes S maßstabsinvariant ist;
eines siebente Vorrichtung zum Ändern der Objektdarstellungs-Haltung in eine andere Haltung bezüglich der zweiten jeweiligen Abbildungshaltungen und
eine achte Vorrichtung zum Bestimmen, ob zwei aufeinanderfolgende Maße der Überlagerung M für verschiedene Haltungen der Objektdarstellung, die von der sechsten Vorrichtung erhalten werden können, sich einander bis zu einem vorgegebenen Schwellenwert nähern oder ein vorgegebenes Konvergenzkriterium erfüllen.

15. Vorrichtung nach dem vorhergehenden Anspruch, wobei die ersten Abbildungsdaten interoperativ erfassbar sind und/oder die zweiten Abbildungsdaten aus einer voroperativ erfassbaren Objektdarstellung rekonstruierbar sind.

16. Vorrichtung nach den zwei vorhergehenden Ansprüchen, wobei das Ähnlichkeitsmaß S und das Abstandsmaß D als

$$M = S/(a + D)$$

zu dem Maß der Überlagerung M kombinierbar sind, wobei a eine vorgegebene Konstante ist.

17. Vorrichtung nach einem der drei vorhergehenden Ansprüche, wobei die Maßstabsinvarianz wenigstens bezüglich des Ähnlichkeitsmaßes S die Maßstabsinvarianz in den Ordnungsrelationen zwischen den Maßen der Überlagerung M wenigstens bezüglich des Ähnlichkeitsmaßes S umfasst.

18. Vorrichtung nach einem der vier vorhergehenden Ansprüche, die ferner umfasst:

eine neunte Vorrichtung zum Erfassen der relativen Verschiebungen des Objekts, und
eine zehnte Vorrichtung zum dementsprechenden Anpassen der Objektdarstellungs-Haltung.

19. Vorrichtung nach einem der fünf vorhergehenden Ansprüche, wobei die relativen Verschiebungen des Objekts über eine Markierung (153), die fest an dem Objekt befestigt ist, mittels eines Positionsabtastsystems oder eines Navigationssystems erfassbar sind.

20. Vorrichtung nach einem der sechs vorhergehenden Ansprüche, wobei das Objekt ein Körper eines Patienten ist.

21. Vorrichtung nach einem der sieben vorhergehenden Ansprüche, wobei die räumliche Darstellung des Objekts eine Entscheidungsregel und mehrere Volumenelemente, die als Voxel bezeichnet werden und die in Scheiben aufgestapelt sind, die Zeilen und Spalten umfassen, umfasst, wobei jedes Voxel wenigstens einen Wert führt und die Entscheidungsregel die Mitgliedschaft jedes Voxels in dem Objekt in Übereinstimmung mit dem wenigstens einen Wert des Voxels bestimmt.

22. Vorrichtung nach dem vorhergehenden Anspruch, wobei die Voxel von Abbildungsvorrichtungen unter

Verwendung der Computertomographie (CT), der Magnetresonanz (MR), der Einzel-Photon-Emissionscomputertomographie (SPECT) oder der Positronenemissionstomographie (PET) erhalten werden können.

23. Vorrichtung nach einem der neun vorhergehenden Ansprüche, wobei die ersten Abbildungsdaten Ultraschallbilder oder Fluoroskopie-Radiogramme umfassen und die zweiten Abbildungsdaten digital rekonstruierte Bilder oder digital rekonstruierte Radiogramme (DRRs) umfassen und/oder wobei die ersten jeweiligen Abbildungshaltungen im Wesentlichen die gleichen Positionen und die gleichen Orientierungen relativ zueinander wie die zweiten jeweiligen Abbildungshaltungen annehmen.

24. Vorrichtung nach einem der zehn vorhergehenden Ansprüche, wobei das Ähnlichkeitsmaß S zwischen den ersten und den zweiten Abbildungsdaten durch das Korrelieren entsprechender Paare der ersten und der zweiten Abbildungsdaten erhalten werden kann und/oder wobei das Abstandsmaß D zwischen dem wenigstens einen Punkt und einer Oberfläche der Objektdarstellung in der Objektdarstellungs-Haltung durch den euklidischen Abstand zwischen dem Punkt und der Oberfläche der Objektdarstellung in dem Fall eines einzelnen Punktes und andernfalls durch das Mitteln der euklidischen Abstände zwischen mehr als einem Punkt und der Oberfläche der Objektdarstellung erhalten werden kann.

25. Vorrichtung nach einem der elf vorhergehenden Ansprüche, wobei der wenigstens eine Punkt auf der Oberfläche des Objekts unter Verwendung eines Positionsabtastsystems oder eines Navigationssystems lokalisierbar ist.

26. Computerprogrammprodukt, das Programmcodemittel zum Ausführen der Verfahrensschritte nach einem der Ansprüche 1 bis 13 umfasst, wenn das Programm in einem Computer ausgeführt wird, oder um einen Computer zu veranlassen, als die Vorrichtung nach einem der Ansprüche 14 bis 25 zu arbeiten, wenn das Programm in einem Computer ausgeführt wird.

27. Computerprogrammprodukt, das Programmcodemittel umfasst, nach dem vorhergehenden Anspruch, die auf einem computerlesbaren Datenträger aufgezeichnet sind.

Revendications

1. Procédé de détermination, dans un espace d'opération tridimensionnel, d'une mesure de superposition M entre un objet ou une partie de celui-ci, appelé objet, et une représentation spatiale de l'objet, appelée représentation d'objet, dans une pause de représentation d'objet, une pause comprenant une position et une orientation dans un espace d'opération, le procédé comprenant :

une étape a) de prise, dans des premières pauses d'imagerie respectives, de premières données d'imagerie de l'objet ;
une étape b) de prise, dans des deuxièmes pauses d'imagerie respectives, de deuxièmes données d'imagerie comparables aux premières données d'imagerie qui sont reconstruites numériquement à partir de la représentation d'objet dans la pause de représentation d'objet ;
une étape c) d'obtention d'une mesure de similarité S entre les premières et deuxièmes données d'imagerie ;
une étape d) d'acquisition, dans un espace d'opération, d'une position d'au moins un point indiqué sur la surface de l'objet ;
une étape e) d'obtention d'une mesure de distance D entre une position d'au moins un point dans un espace d'opération et une surface de la représentation d'objet dans la pause de représentation d'objet, et
caractérisé en ce que le procédé comprend en outre :

une étape f) d'obtention d'une mesure de superposition M par une combinaison multiplicative de la mesure de similarité S et de la mesure de distance D ;
dans lequel la combinaison de la mesure de similarité S et de la mesure de distance D est invariante à l'échelle par rapport à la mesure de similarité S.

2. Procédé selon la revendication précédente, comprenant en outre l'alignement de l'objet et de la pause de représentation d'objet dans un espace d'opération, comprenant :

une étape g) d'exécution conjointement d'une étape h) et de répétition des étapes b), c), e) et f) un nombre prédéterminé de fois ou jusqu'à ce que deux mesures de superposition M consécutives obtenues à l'étape f) s'approchent l'une de l'autre jusqu'à un seuil prédéterminé ou jusqu'à ce qu'un critère de convergence prédéterminé soit satisfait ; et
une étape h) de changement de la pause de représentation d'objet à une pause différente en relation avec les deuxièmes pauses d'imagerie respectives.

3. Procédé selon l'une quelconque des revendications précédentes, dans lequel les premières données d'imagerie sont acquises entre opérations et/ou les deuxièmes données d'imagerie sont reconstruites à partir d'une représentation d'objet acquise avant opération.

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure de similarité S et la mesure de distance D sont combinées à la mesure de superposition M en tant que

$$M = S/(a + D),$$

où a est une constante prédéterminée.

5. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'invariance à l'échelle au moins par rapport à la mesure de similarité S comprend une invariance à l'échelle d'ordonnancement des relations entre les mesures de superposition M au moins par rapport à la mesure de similarité S.

6. Procédé selon l'une quelconque des revendications précédentes, consistant en outre à :

acquérir des déplacements relatifs de l'objet, et adapter la pause de représentation d'objet en conséquence.

7. Procédé selon la revendication précédente, dans lequel les déplacements relatifs de l'objet sont acquis par l'intermédiaire d'un marqueur (153) attaché fixement à l'objet au moyen d'un système de détection de position ou d'un système de navigation.

8. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'objet est un corps d'un patient.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel la représentation spatiale de l'objet comprend une règle de décision et une pluralité d'éléments de volume, appelés voxels, empilés en tranches comprenant des rangées et des colonnes, chaque voxel portant au moins une valeur, et la règle de décision déterminant l'appartenance de chaque voxel à l'objet conformément à ladite au moins une valeur du voxel.

10. Procédé selon la revendication précédente, dans lequel les voxels sont obtenus par imagerie de l'objet en utilisant la tomodensitométrie (CT), la résonance magnétique (RM), la gammatomographie (SPECT), ou la tomographie d'émission de positons (PET).

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel les premières données d'imagerie comprennent des images ultrasonores ou des radiographies de fluoroscopie et les deuxièmes radiographies comprennent des images numériques reconstruites ou des radiographies reconstruites numériquement (DRR), et/ou dans lequel les premières pauses d'imagerie respectives adoptent essentiellement les mêmes position et orientations les unes par rapport aux autres que les deuxièmes pauses d'imagerie respectives.

12. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure de similarité S entre les premières et deuxièmes données d'imagerie est obtenue en corrélant des paires correspondantes de premières et deuxièmes données d'imagerie, et/ou dans lequel la mesure de distance D entre ledit au moins un point et une surface de la représentation d'objet dans la pause de représentation d'objet est obtenue par la distance euclidienne du point et de la surface de la représentation d'objet dans le cas d'un point unique et autrement en moyennant les distances euclidiennes de plusieurs points et de la surface de la représentation d'objet.

13. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit au moins un point sur la surface de l'objet est localisé en utilisant un système de détection de position ou un système de navigation.

14. Appareil pour aligner, dans un espace d'opération tridimensionnel, un objet (100) ou une partie de celuici, appelé objet, et une représentation spatiale de l'objet, appelée représentation d'objet, dans une pause de représentation d'objet, une pause comprenant une position et une orientation dans un espace d'opération, l'appareil comprenant :

un premier dispositif pour prendre, dans des premières pauses d'imagerie respectives, des premières données d'imagerie (110) de l'objet ;
un deuxième dispositif pour prendre, dans des deuxièmes pauses d'imagerie respectives, des deuxièmes données d'imagerie comparables aux premières données d'imagerie qui peuvent être reconstruites numériquement à partir de la représentation d'objet dans la pause de représentation d'objet ;
un troisième dispositif pour obtenir une mesure de similarité S entre les premières et deuxièmes données d'imagerie ;
un quatrième dispositif pour acquérir, dans un espace d'opération, une position d'au moins un point pouvant être indiqué sur la surface de l'objet ;
un cinquième dispositif pour obtenir une mesure de distance D entre ledit au moins un point et une surface de la représentation d'objet dans la

pause de représentation d'objet ;
un sixième dispositif pour obtenir une mesure de superposition M par une combinaison multiplicative de la mesure de similarité S et de la mesure de distance D qui est invariante à l'échelle par rapport à la mesure de similarité S ;
un septième dispositif pour changer la pause de représentation d'objet en une pause différente en relation avec les deuxièmes pauses d'imagerie respectives ; et
un huitième dispositif pour déterminer si deux mesures consécutives de superposition M pour différentes pauses de la représentation d'objet pouvant être obtenues par le sixième dispositif s'approchent l'une de l'autre jusqu'à un seuil prédéterminé, ou satisfont à un critère de convergence prédéterminé.

15. Appareil selon la revendication précédente, dans lequel les premières données d'imagerie peuvent être acquises entre opérations et/ou les deuxièmes données d'imagerie peuvent être reconstruites à partir d'une représentation d'objet pouvant être acquise avant opération.

16. Appareil selon les deux revendications précédentes, dans lequel la mesure de similarité S et la mesure de distance D peuvent être combinées à la mesure de superposition M en tant que

$$M = S/(a + D),$$

où a est une constante prédéterminée.

17. Appareil selon l'une quelconque des trois revendications précédentes, dans lequel l'invariance à l'échelle au moins par rapport à la mesure de similarité S comprend une invariance à l'échelle d'ordonnancement des relations entre les mesures de superposition M au moins par rapport à la mesure de similarité S.

18. Appareil selon l'une quelconque des quatre revendications précédentes, comprenant en outre :

un neuvième dispositif pour acquérir des déplacements relatifs de l'objet, et
un dixième dispositif pour adapter la pause de représentation d'objet en conséquence.

19. Appareil selon l'une quelconque des cinq revendications précédentes, dans lequel les déplacements relatifs de l'objet peuvent être acquis par l'intermédiaire d'un marqueur (153) attaché fixement à l'objet au moyen d'un système de détection de position ou d'un système de navigation.

20. Appareil selon l'une quelconque des six revendications précédentes, dans lequel l'objet est un corps d'un patient.

21. Appareil selon l'une quelconque des sept revendications précédentes, dans lequel la représentation spatiale de l'objet comprend une règle de décision et une pluralité d'éléments de volume, appelés voxels, empilés en tranches comprenant des rangées et des colonnes, chaque voxel portant au moins une valeur, et la règle de décision déterminant l'appartenance de chaque voxel à l'objet conformément à ladite au moins une valeur du voxel.

22. Appareil selon la revendication précédente, dans lequel les voxels peuvent être obtenus par des dispositifs d'imagerie en utilisant la tomodensitométrie (CT), la résonance magnétique (RM), la gammatomographie (SPECT), ou la tomographie d'émission de positons (PET).

23. Appareil selon l'une quelconque des neuf revendications précédentes, dans lequel les premières données d'imagerie comprennent des images ultrasonores ou des radiographies de fluoroscopie et les deuxièmes données d'imagerie comprennent des images reconstruites numériquement ou des radiographies reconstruites numériquement (DRR), et/ou dans lequel les premières pauses d'imagerie respectives adoptent essentiellement les mêmes position et orientations les unes par rapport aux autres que les deuxièmes pauses d'imagerie respectives.

24. Appareil selon l'une quelconque des dix revendications précédentes, dans lequel la mesure de similarité S entre les premières et deuxièmes données d'imagerie est obtenue en corrélant des paires correspondantes de premières et deuxièmes données d'imagerie, et/ou dans lequel la mesure de distance D entre ledit au moins un point et une surface de la représentation d'objet dans la pause de représentation d'objet peut être obtenue par la distance euclidienne du point et de la surface de la représentation d'objet dans le cas d'un point unique et autrement en moyennant les distances euclidiennes de plusieurs points et de la surface de la représentation d'objet.

25. Appareil selon l'une quelconque des onze revendications précédentes, dans lequel ledit au moins un point sur la surface de l'objet peut être localisé en utilisant un système de détection de position ou un système de navigation.

26. Produit-programme d'ordinateur comprenant des moyens formant code de programme pour exécuter les étapes de procédé selon l'une quelconque des revendications 1 à 13, lorsque le programme est exécuté sur un ordinateur, ou pour amener un ordinateur à fonctionner en tant qu'appareil selon l'une quelconque des revendications 14 à 25, lorsque le programme est exécuté sur un ordinateur.

27. Produit-programme d'ordinateur comprenant des moyens formant code de programme selon la revendication précédente qui est enregistré sur un support de données pouvant être lu par un ordinateur.

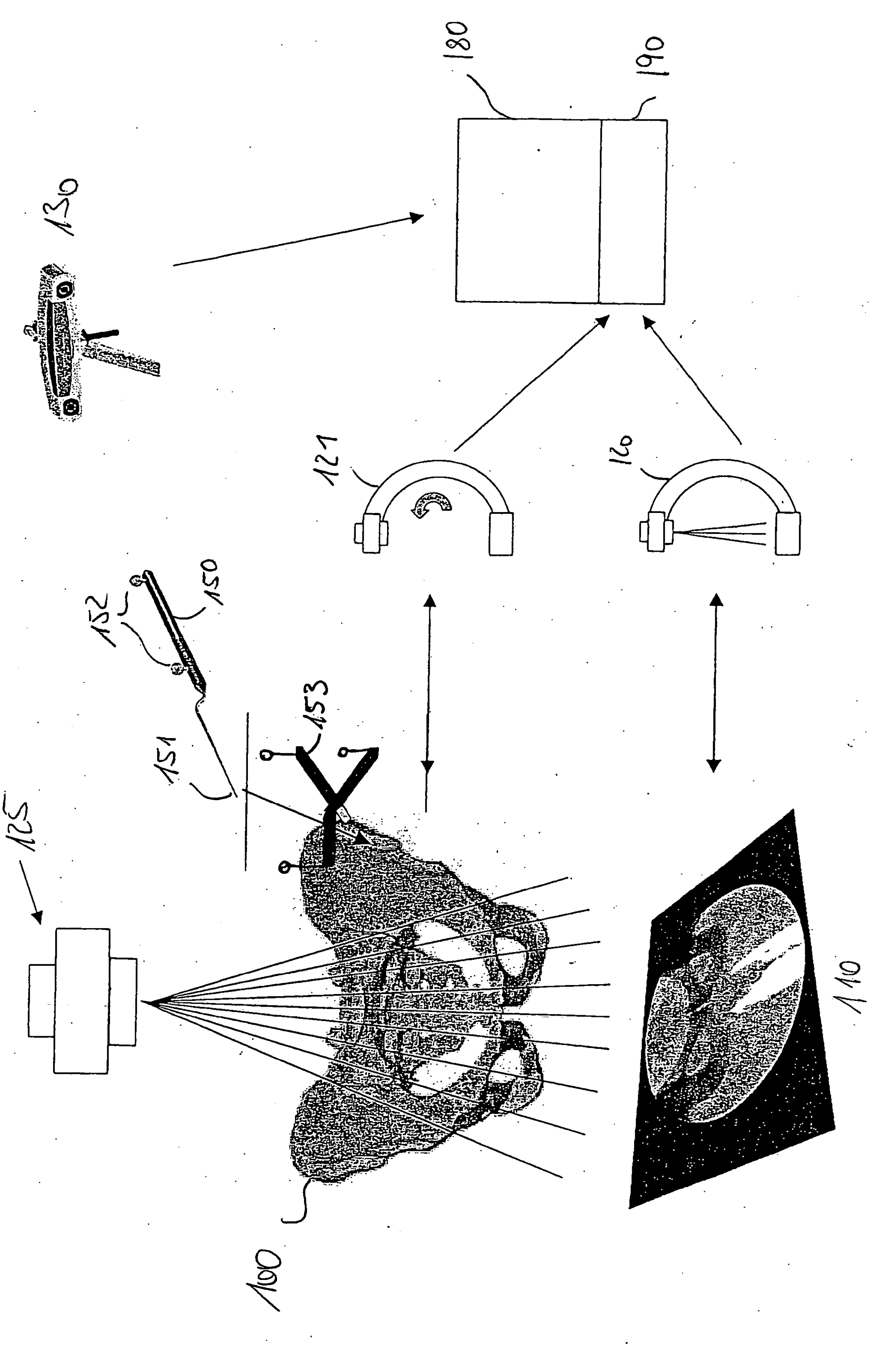

Fig. 1

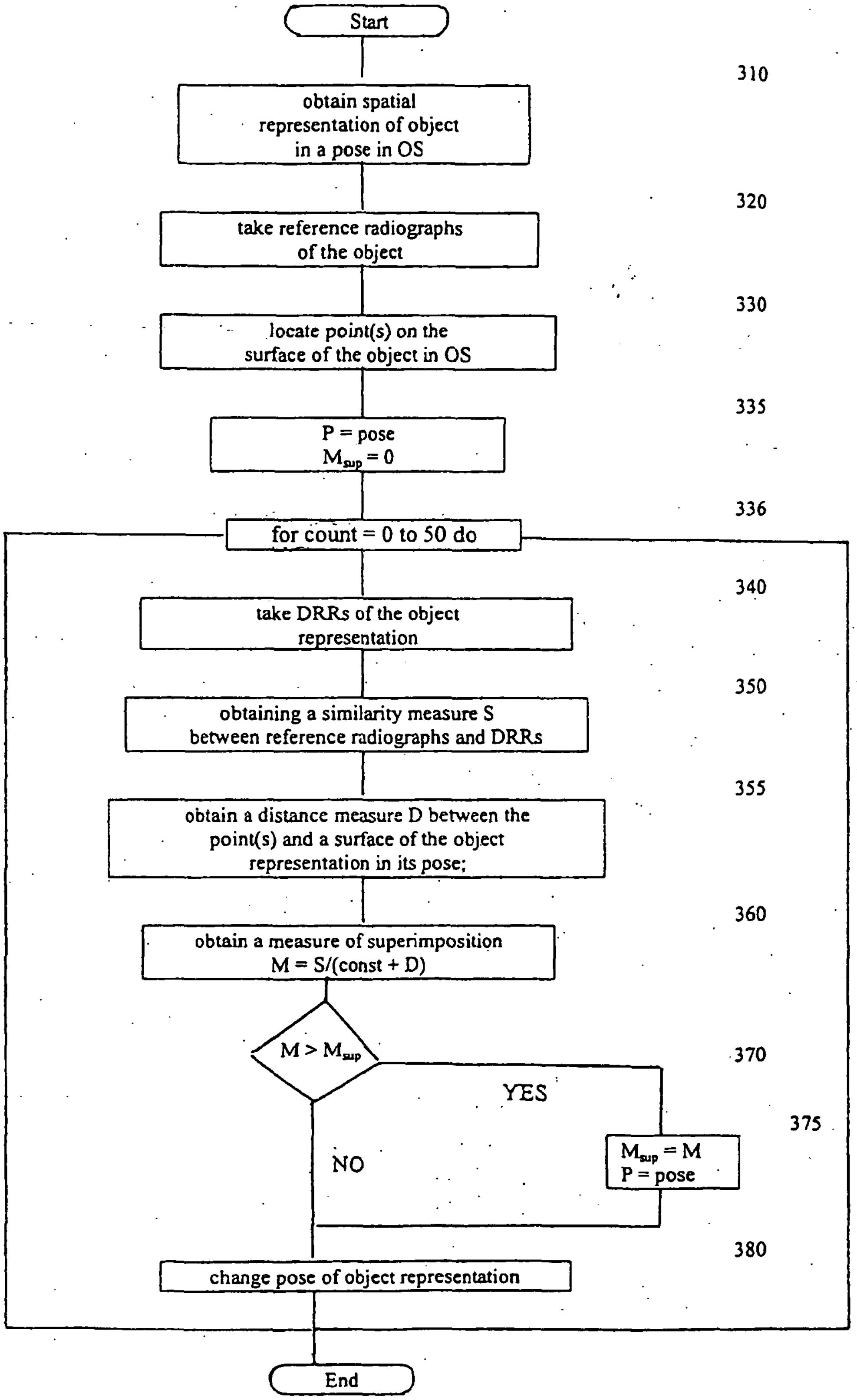
Start
310
obtain spatial representation of object in a pose in OS
320
take reference radiographs of the object
330
locate point(s) on the surface of the object in OS
335
P = pose
$M_{sup} = 0$
336
for count = 0 to 50 do
340
take DRRs of the object representation
350
obtaining a similarity measure S between reference radiographs and DRRs
355
obtain a distance measure D between the point(s) and a surface of the object representation in its pose;
360
obtain a measure of superimposition
M = S/(const + D)
370
$M > M_{sup}$
YES
NO
375
$M_{sup} = M$
P = pose
380
change pose of object representation
End

Fig. 2

REFERENCES CITED IN THE DESCRIPTION

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